

**ELECTRICAL AND COMPUTER ENGINEERING
DEPARTMENT**



CLEMSON UNIVERSITY

CLEMSON, SC 29634-0915

INTERIM

TR-110193-3570F

IN-32-CR

27 Cit.

191241

19P

**WINDSHEAR DETECTION RADAR
SIGNAL PROCESSING STUDIES - FINAL REPORT**

by

Ernest G. Baxa, Jr.

**Radar Systems Laboratory
Technical Report No. 18**

N94-16022

Unclass

G3/32 0191241

(NASA-CR-194615) WINDSHEAR
DETECTION RADAR SIGNAL PROCESSING
STUDIES Final Technical Report No.
18, 16 Nov. 1988 - 31 Oct. 1993
(Clemson Univ.) 19 p



Windshear Detection Radar Signal Processing Studies - Final Report

by

Ernest G. Baxa, Jr.

**Technical Report #18
November 1, 1993**

**Radar Systems Laboratory
Electrical and Computer Engineering Department
Clemson University
Clemson, SC 29634-0915**



**Windshear Detection Radar Signal Processing Studies
Grant NAG-1-928
National Aeronautics and Space Administration
Langley Research Center
Hampton, VA 23665**

ABSTRACT

This final report briefly summarizes research work at Clemson in the Radar Systems Laboratory under the NASA Langley Research Grant NAG-1-928 in support of the Antenna and Microwave Branch, Guidance and Control Division, program to develop airborne sensor technology for the detection of low altitude windshear. A bibliography of all publications generated by Clemson personnel is included. An appendix provides abstracts of all publications.

TABLE OF CONTENTS

	Page
TITLE PAGE	i
ABSTRACT	ii
GRANT RESEARCH DESCRIPTION	1
BIBLIOGRAPHY OF PUBLICATIONS	2
APPENDIX - ABSTRACTS OF PUBLICATIONS	5

GRANT RESEARCH DESCRIPTION

The Radar Systems Laboratory effort has been directed primarily at the NASA task of demonstrating the feasibility of airborne pulse Doppler radar for the purpose of detecting low altitude windshear. The specific research within the Laboratory has involved signal processing aspects of this task. Ground clutter returns have been identified as a major interference with weather radar particularly when the weather events have very low radar reflectivity. In the airspace near major urban airports the clutter environment is frequently complicated by the presence of "discrete clutter", e.g., clutter return from moving objects on the ground, which compounds the problem of clutter rejection filtering, particularly in low weather signal to clutter ratio conditions. Research work has considered the effect of radar system phase instabilities on the errors of windspeed parameter estimates needed to characterize the windfield. Various clutter rejection schemes including conventional notch filtering, complex coefficient linear notch filters, adaptive filtering based on linear modelling of ground clutter returns, and the use of non-linear signal processing have been considered. This work has involved use of new advances in signal processing which are appropriate for non-stationary signal environments. Some innovative windspeed parameter estimation techniques have been investigated including an application of pattern recognition techniques in conjunction with autoregressive modelling. The major thrust has been directed at developing signal processing algorithms which will enhance the ability to detect hazardous windshear in very low signal to clutter ratio environments. In this situation conventional clutter rejection filtering can potentially reduce the sensitivity of the detector to the point that there is not sufficient weather return to get a stable windspeed estimate.

Research work accomplished during the grant period has related to developing improved clutter rejection techniques as well as evaluating more conventional techniques [3,6,7,9,10,13,16,20,22,24]. Improvements in windspeed detection have been considered [2,5,11,12,14,16]. Innovative signal processing schemes have been considered [1,9,10,13,14-17,19,21,23,25]. In addition some work under the grant can perhaps better be described as basic research in signal processing [4,8,11,14,22,23,25].

In addition to published results of research work, a number of Clemson graduate students in electrical engineering have received grant support for their research work. Two students have completed the Ph.D. degree in electrical engineering while working under the grant support and two other supported students are Ph.D. candidates and should finish their dissertation work within the next year. Five students have completed requirements for the Master of Science degree and another MS level student will complete degree requirements within the next year. In addition several undergraduate students have been involved in supporting grant activity on an unsupported basis.

BIBLIOGRAPHY OF PUBLICATIONS

1. E.G. Baxa, Jr. and J. Lee, "The Measurement of Windspeed Gradient with Low PRF Radar," Proc. Southeast. Symp. on Sys. Theory, SSST-88, Charlotte NC, March 1988.
2. J. Lee and E.G. Baxa, Jr., "Preliminary Analysis of Windshear Detection Signal Processing Considering Doppler Weather Radar," Radar Sys. Lab. TR No.8, Research Triangle Inst. subcontract 4-414U-3042 under NASA cont. NAS1-17639, Clemson Univ., September 1988.
3. E.G. Baxa, Jr., "Clutter Filter Design Considerations for Airborne Doppler Radar Detection of Windshear," Second Combined Manufacturer's and Technology Airborne Windshear Review Meeting, sponsored by NASA Langley Research Center and the FAA, Williamsburg, VA, October 18-20, 1988.
4. E.G. Baxa, Jr., "Resolution of the STUSE Algorithm Used in Spectrum Estimation," Radar Sys. Lab. TR No.9, NASA grant NAG-1-928, Clemson Univ., December 1988.
5. J. Lee and E.G. Baxa, Jr., "Pulse-pair Spectral Estimates in the Presence of Radar Oscillator Phase Jitter," Proc. 21st Southeast. Symp. on Sys. Theory, Florida St. Univ., Tallahassee, March 1989.
6. W.T. Davis and E.G. Baxa, Jr., "Effects of Filtering on Estimating Spectral Moments of Meteorological Doppler Spectra," Proc. 21st Southeast. Symp. on Sys. Theory, Florida St. Univ., Tallahassee, March 1989.
7. W.T. Davis, "The Effects of Clutter-rejection Filtering on Estimating Weather Spectrum Parameters," NASA CR-186212, Radar Sys. Lab. TR no. 10, NASA LaRC grant NAG-1-928 and NGT-70055, Clemson Univ., July 1989.
8. E.G. Baxa, Jr., "On Implementation of the Discrete Fourier Transform - The STUSE Algorithm for Spectral Estimation," IEEE Trans. on Acoust., Speech, and Sig. Proc., vol.37, no. 11, pp. 1763-1765, November 1989.
9. B.M. Keel, "Adaptive Clutter Rejection Filters for Airborne Doppler Weather Radar Applied to the Detection of Low Altitude Windshear," NASA CR-186211, Radar Sys. Lab. TR no. 11, NASA LaRC grant NAG-1-928, Clemson Univ., December 1989.
10. B.M. Keel and E.G. Baxa, Jr., "Adaptive Least Square Complex Lattice Clutter Rejection Filters Applied to the Radar Detection of Low Altitude Windshear," Proc. 1990 Intl. Conf. Acoust., Speech, Sig. Proc., ICASSP-90, pp. 1469-1472, Albuquerque, NM, April 1990.
11. J. Lee, "Analysis and Improved Design Considerations for Airborne Pulse Doppler Radar Signal Processing in the Detection of Hazardous Windshear," NASA CR-

- 186792, Radar Sys. Lab. TR no. 12, NASA grant NAG-1-928, Clemson Univ., May 1990.
12. J. Lee and E.G. Baxa, Jr., "Phase Noise Effects on Turbulent Weather Radar Spectrum Parameter Estimation," Proc. 1990 IEEE Intl. Radar Conf., pp. 345-350, Arlington, VA, May 7-10, 1990.
 13. E.G. Baxa, Jr., "Signal Processing Techniques for Clutter Filtering and Windshear Detection," Third Combined Manufacturer's and Technology Airborne Windshear Review Meeting, sponsored by NASA Langley Research Center and the FAA, Hampton, VA, October 16-18, 1990.
 14. E.G. Baxa, Jr. and J. Lee, "The Pulse Pair Algorithm as a Robust Estimator of Turbulent Weather Spectral Parameters using Airborne Pulse Doppler Radar," NASA CR-4382, DOT/FAA/RD-91/17, Radar Sys. Lab. TR no.13, NASA grant NAG-1-928, Clemson Univ., June 1991.
 15. D.D. Aalfs, "Real Time Processing of Radar Return on a Parallel Computer," NASA CR-4456, DOT/FAARD-92/20, Radar. Sys. Lab. TR no.14, NASA LaRC grant NAG-1-928 and NGT-50414, Clemson Univ., July 1991.
 16. E.G. Baxa, Jr., "Airborne Pulsed Doppler Radar Detection of Low Altitude Windshear - A Signal Processing Problem," Digital Signal Processing, Academic Press, Inc., vol. 1, no. 4, pp. 186-197, October 1991.
 17. M.W. Kunkel, "Spectrum Modal Analysis for the Detection of Low-Altitude Windshear with Airborne Doppler Radar," NASA CR-4457, DOT/FAARD-92/21, Radar Sys. Lab. TR no. 15, NASA grant NAG-1-928, Clemson Univ., February 1992.
 18. E.G. Baxa, Jr., "Detection of Low Altitude Windshear - Overcoming a Major Safety Hazard in Terminal Area Aircraft Operation," Piedmont Section, IEEE, Greenville, SC, February 20, 1992.
 19. E.G. Baxa, Jr., "Signal Processing for Airborne Doppler Radar Detection of Hazardous Windshear as Applied to NASA 1991 Radar Flight Experimental Data," Fourth Combined Manufacturers' and Technologists' Airborne Windshear Review Meeting, sponsored by NASA Langley Research Center and the FAA, Williamsburg, VA, April 14-16, 1992.
 20. A.I. Mackenzie, E.G. Baxa, Jr., and S.D. Harrah, "Characterization of Urban Ground Clutter with New Generation Airborne Doppler Weather Radar," Proceedings IEEE 1993 National Radar Conference, Boston, MA, pp. 51-56, April 1993.
 21. E.G. Baxa, Jr., Y.C. Lai, and M.W. Kunkel, "New Signal Processing Developments in the Detection of Low-Altitude Windshear with Airborne Doppler Radar," Proceedings IEEE 1993 National Radar Conference, Boston, MA, pp. 269-274, April 1993.

22. Y.C. Lai and E.G. Baxa, Jr., "On the Application of the LMS-based Adaptive Noise Canceller in a Nonstationary Environment Associated with Airborne Doppler Weather Radar," Proceedings 1993 IEEE International Conference on Acoustics, Speech, and Signal Processing, Minneapolis, MN, pp. III:25-28, April 1993.
23. K.D. Barnett and E.G. Baxa, Jr., "A Study of the Correlation Dimension of Weather and Ground Clutter Returns in Airborne Radar," Proceedings 26th International Conference on Radar Meteorology, Norman, OK, pp. 247-248, May 1993.
24. D.A. Jamora, "Designing Clutter Rejection Filters with Complex Coefficients for Airborne Pulsed Doppler Weather Radar," NASA CR (in publication), DOT/FAA-93/24, Radar Sys. Lab. TR no. 16, NASA LaRC grant NAG-1-928, Clemson Univ., May 1993.
25. K.D. Barnett, "On the Estimation of the Correlation Dimension and its Application to Radar Reflector Discrimination," NASA CR (in publication), Radar Sys. Lab. TR no. 17, NASA LaRC grant NAG-1-928, Clemson Univ., July 1993.
26. S.D. Harrah, E.M. Bracalente, P.R. Schafner, and E.G. Baxa, Jr., "Description and Availability of Airborne Doppler Radar Data," Progress in Electromagnetics Research Symp., abstract in JPL pub. 93-IT, p 262, Pasadena, CA, July 12-16, 1993.
27. D.D. Aalfs, E.G. Baxa, Jr., and E.M. Bracalente, "Signal Processing Aspects of Windshear Detection," Microwave Journal, vol. 36, no. 9, pp. 76-96, September 1993.

APPENDIX
ABSTRACTS OF PUBLICATIONS

THE MEASUREMENT OF WINDSPEED GRADIENT WITH LOW PRF RADAR ^[1]

E.G. Baxa, Jr. and J. Lee

In determining a wind shear condition with pulse Doppler radar, it may not be necessary to estimate the absolute windspeeds in range cells but only the difference in average windspeed between range cells, i.e., windspeed gradient. Generally the magnitude of the windspeed gradient will be substantially less than the absolute mean windspeed, even for high turbulence environments, thus making it possible to employ low PRF radar with its inherently good ranging capability. Simulated data representing weather radar returns are analyzed to demonstrate some of the potential and problems associated with estimating Doppler difference frequency using a reduced pulse repetition frequency (PRF).

PRELIMINARY ANALYSIS OF WINDSHEAR DETECTION SIGNAL PROCESSING CONSIDERING DOPPLER WEATHER RADAR ^[2]

J. Lee and E. G. Baxa, Jr.

The pulse-pair method for the spectrum estimation is commonly used in weather radar signal processing since it is economical to implement and has been shown to be a maximum likelihood estimator. The phase jitter in a radar oscillator may degrade the performance of this estimator causing erroneous estimation of the spectral moments. This effect is investigated based upon a Gaussian phase noise assumption and upon previously developed estimate error equations associated with the pulse-pair method. This report provides a preliminary analysis of this investigation. Phase noise is shown to degrade the variance of the mean estimate and increase the mean square error of the width estimate. Some variation in this effect is noted as the weather spectrum width is changed. Recommendations are made for developing a more complete understanding of the effect of radar oscillator instabilities on the pulse-pair parameter estimates.

CLUTTER FILTER DESIGN CONSIDERATIONS FOR AIRBORNE DOPPLER RADAR DETECTION OF WINDSHEAR ^[3]

E. G. Baxa, Jr.

The problem of clutter rejection when processing down-looking Doppler radar returns from a low altitude airborne platform is a paramount problem. With radar as a remote sensor for detecting and predicting windshear in the vicinity of an urban airport, dynamic range requirements can exceed 50 dB because of high clutter to signal ratios. This presentation describes signal processing considerations in the presence of distributed and/or discrete clutter interference. Previous analyses have considered conventional range cell processing of radar returns from a rigidly mounted radar platform using either the Fourier or the pulse-pair method to estimate average windspeed and windspeed variation within a cell. Clutter rejection has been based largely upon analyzing a particular environment in the vicinity of the radar and employing a variety of techniques to reduce interference effects including notch filtering, Fourier domain line editing, and use of clutter maps. For the airborne environment the clutter characteristics may be somewhat different. Conventional

clutter rejection methods may have to be changed and new methods will probably be required to provide useful signal to noise ratios. Various considerations are described. A major thrust has been to evaluate the effect of clutter rejection filtering upon the ability to derive useful information from the post filter radar data. This analysis software is briefly described. Finally, some ideas for future analysis are considered including the use of adaptive filtering for clutter rejection and the estimation of windspeed spatial gradient directly from radar returns as a means of reducing the effects of clutter on the determination of a windshear hazard.

RESOLUTION OF THE STUSE ALGORITHM USED IN SPECTRUM ESTIMATION ^[4] E. G. Baxa, Jr.

The discrete short-time Fourier transform implemented as the STUSE (short-time unbiased spectrum estimation) algorithm, which includes both Fourier domain coherent smoothing and power domain incoherent smoothing, is examined in terms of its resolution capability in power spectrum estimation. An analysis of the STUSE algorithm in terms of the effective spectral window allows insight into how the influence of the finite window length on a spectral estimate can be lessened by linearly combining biased estimates. Computational requirements are compared to the WOSA (weighted overlapped segment averaging) algorithm which has been previously characterized as a special case of the STUSE algorithm. A complex data implementation of the STUSE algorithm, typical of what would be required to process a sample function of a bandpass stochastic signal, such as a Doppler weather radar IF output, is considered in terms of bias, frequency resolution, and computational load. The STUSE algorithm appears to offer reduced leakage bias estimates as compared to WOSA without significant additional computational load.

PULSE-PAIR SPECTRAL-ESTIMATES IN THE PRESENCE OF RADAR OSCILLATOR PHASE JITTER ^[5] J. Lee and E. G. Baxa, Jr.

The pulse-pair method for spectrum estimation is commonly used in Doppler weather radar signal processing since it is economical to implement and has been shown to be a maximum likelihood estimator. High precision of weather spectrum moment estimation is important in the use of weather radar for hazardous windshear detection. The phase jitter in a radar oscillator may degrade the performance of the pulse-pair estimator causing erroneous estimation of the spectral moments. This effect is investigated based upon previously developed estimate error equations associated with the pulse-pair method.

EFFECTS OF FILTERING ON ESTIMATING SPECTRAL MOMENTS OF METEOROLOGICAL DOPPLER SPECTRA ^[6] W. T. Davis and E. G. Baxa, Jr.

An airborne weather radar operating at a low altitude in the vicinity of an urban terminal area may be subjected to extremely high levels of ground clutter interference.

Some means of rejecting ground clutter is paramount before processing pulse Doppler radar in-phase and quadrature-phase (Q) data using the pulse-pair method, a time-domain estimation technique of spectral moments. This paper describes an on-going effort to develop a means of evaluating a clutter-rejection filter based upon how it effects the pulse-pair processor spectral estimates of weather data in the absence of clutter. Several clutter-rejection filters are evaluated and compared to a baseline ideal filter. The loss of sensitivity, a measure of the signal power lost due to filtering, is also considered in the analysis.

THE EFFECTS OF CLUTTER-REJECTION FILTERING ESTIMATING WEATHER SPECTRUM PARAMETERS ^[7]

W. T. Davis

This thesis investigates the effects of clutter-rejection filtering on estimating the weather parameters from pulse Doppler radar measurement data. The pulse pair method of estimating the spectrum mean and spectrum width of the weather is emphasized. The loss of sensitivity, a measure of the signal power lost due to filtering, is also considered. A flexible software tool developed to investigate these effects is described. It allows for simulated weather radar data, in which the user specifies an underlying truncated Gaussian spectrum, as well as for externally generated data which may be real or simulated. The filter may be implemented in either the time or the frequency domain. The software tool is validated by comparing unfiltered spectrum mean and width estimates to their true values, and by reproducing previously published results. The effects on the weather parameter estimates using simulated weather-only data are evaluated for five filters: an "idea" filter, two infinite impulse response filters, and two finite impulse response filters. Results considering external data, consisting of weather and clutter data, are evaluated on a range cell by range cell basis. Finally, it is shown theoretically and by computer simulation that a linear phase response is not required for a clutter rejection filter preceding pulse-pair parameter estimation.

ON IMPLEMENTATION OF THE DISCRETE FOURIER TRANSFORM - THE STUSE ALGORITHM FOR SPECTRAL ESTIMATION ^[8]

E. G. Baxa, Jr.

The discrete short-time Fourier transform implemented as the STUSE (short-time unbiased spectrum estimation) algorithm, which includes both Fourier domain coherent smoothing and power domain incoherent smoothing, is examined in terms of its resolution capability in power spectrum estimation. An analysis of the STUSE algorithm in terms of the effective spectral window allows insight into how the influence of the finite window length on a spectral estimate can be lessened by linearly combining biased estimates. Comparison is made to the weighted overlapped segment averaging (WOSA) algorithm which has been previously characterized as a special case of the STUSE algorithm.

ADAPTIVE CLUTTER REJECTION FILTERS FOR AIRBORNE DOPPLER WEATHER RADAR APPLIED TO THE DETECTION OF LOW ALTITUDE WINDSHEAR ^[9]

B. M. Keel

This thesis presents an optimum adaptive clutter rejection filter for use with airborne Doppler weather radar. The radar system is being designed to operate at low altitudes for the detection of windshear in an airport terminal area where ground clutter returns may mask the weather return. The coefficients of the adaptive clutter rejection filter are obtained using a complex form of a square root normalized recursive least squares lattice estimation algorithm which models the clutter return data as an autoregressive process. The normalized lattice structure implementation of the adaptive modeling process for determining the filter coefficients assures that the resulting coefficients will yield a stable filter and offers possible fixed point implementation. A 10th order FIR clutter rejection filter indexed by geographical location is designed through autoregressive modeling of simulated clutter data. Filtered data, containing simulated dry microburst and clutter return, are analyzed using pulse-pair estimation techniques. To measure the ability of the clutter rejection filters to remove the clutter, results are compared to pulse-pair estimates of windspeed within a simulated dry microburst without clutter. In the filter evaluation process, post-filtered pulse-pair width estimates and power levels are also used to measure the effectiveness of the filters. The results presented support the use of an adaptive clutter rejection filter for reducing the clutter induced bias in pulse-pair estimates of windspeed. The adaptive clutter rejection filter is also shown to perform better than one clutter rejection filter commonly used in land based air traffic control radar systems.

ADAPTIVE LEAST SQUARE COMPLEX LATTICE CLUTTER REJECTION FILTERS APPLIED TO THE RADAR DETECTION OF LOW ALTITUDE WINDSHEAR ^[10]

B.M. Keel and E.G. Baxa, Jr.

This paper addresses the use of an adaptive complex clutter rejection filter for reducing the ground clutter bias in pulse-pair mean windspeed estimates of weather return data collected by low altitude airborne pulsed Doppler radar. A complex form of the square root normalized recursive least squares lattice estimation algorithm, which models the ground clutter as a low order autoregressive process, is used to obtain the filter coefficients. Simulated dry microburst return and clutter return based on data taken from the Denver Stapleton airport are used to assess the capabilities of the clutter rejection filters. Results indicate that the clutter process is low order and that the model based, complex valued, rejection filters offer potential for stable, real time implementation.

ANALYSIS AND IMPROVED DESIGN CONSIDERATIONS FOR AIRBORNE PULSE DOPPLER RADAR SIGNAL PROCESSING IN THE DETECTION OF HAZARDOUS WINDSHEAR ^[11]

J. Lee

High resolution windspeed profile measurements are needed to provide reliable detection of hazardous low-altitude windshear with an airborne pulse Doppler radar.

The system phase noise in a Doppler weather radar may degrade the spectrum moment estimation quality and the clutter cancellation capability which are important in windshear detection. Also, the bias due to weather return Doppler spectrum skewness may cause large errors in pulse pair spectral parameter estimates. These effects are analyzed for the improvement of an airborne Doppler weather radar signal processing design. This dissertation also presents a method for the direct measurement of windspeed gradient using low pulse repetition frequency (PRF) radar. This spatial gradient is essential in obtaining the windshear hazard index. As an alternative, the modified Prony method is suggested as a spectrum mode estimator for both the clutter and weather signal. Estimation of Doppler spectrum, modes may provide the desired windshear hazard information without the need of any preliminary processing requirement such as clutter filtering. The results obtained by processing a NASA simulation model output support consideration of mode identification as one component of a windshear detection algorithm.

PHASE NOISE EFFECTS ON TURBULENT WEATHER RADAR SPECTRUM PARAMETER ESTIMATION^[12]

J. Lee and E. G. Baxa, Jr.

Accurate weather spectrum moment estimation is important in the use of weather radar for hazardous windshear detection. The pulse pair and fast Fourier transform (FFT) methods for spectrum moment estimation are most commonly used in Doppler weather radar signal processing since both techniques have shown a good performance capability. The pulse pair method is much simpler and faster, but the FFT method is preferred in some cases where the pulse pair method may yield meaningless results. The phase jitter in a radar oscillator may degrade the performance of the pulse pair estimator or the FFT estimator, causing erroneous estimation of the spectral moments. This effect is investigated based upon previously developed estimate error equations associated with the pulse pair and FFT methods.

SIGNAL PROCESSING TECHNIQUES FOR CLUTTER FILTERING AND WINDSHEAR DETECTION^[13]

E. G. Baxa, Jr.

It has been argued that the windshear hazard factor is a sufficient statistic for detecting hazardous windshear conditions. The hazard factor is computed by estimating the spatial gradient of windspeed across the radar sector of coverage. With the airborne Doppler radar, one approach is to use estimates of windspeed within each range resolution cell as a basis for estimating this spatial gradient. Currently, research is directed at understanding how to obtain the best possible estimate of windspeed conditions within a range cell. Conventional pulse-pair processing obtains mean estimates of windspeed. The presence of strong ground clutter in a low altitude airborne radar return can significantly bias these mean estimates. One thrust of this effort has involved use of adaptive clutter rejection filters based upon auto-regressive modelling of the ground clutter returns. This offers the potential for using very simple finite impulse response digital filters to eliminate highly specular ground clutter returns.

For situations where the weather return is quite low, e.g., the "dry" microburst, clutter rejection filtering can reduce the weather return signal levels to the extent that the variance of the mean estimates is quite large. Research is involved with using mode estimates, i.e., estimates of the most probable windspeed, in each range cell in determining the hazard factor. An extended Prony algorithm is discussed. It is based upon modelling the radar return as a time series and appears to offer potential for improving hazard factor estimates in the presence of strong clutter returns.

THE PULSE PAIR ALGORITHM AS A ROBUST ESTIMATOR OF TURBULENT WEATHER SPECTRAL PARAMETERS USING AIRBORNE PULSE DOPPLER RADAR^[14]

E. G. Baxa, Jr. and J. Lee

The pulse pair method for spectrum parameter estimation is commonly used in pulse Doppler weather radar signal processing since it is economical to implement and can be shown to be a maximum likelihood estimator. With the use of airborne weather radar for windshear detection, the turbulent weather and strong ground clutter return spectrum differs from that assumed in its derivation, so the performance robustness of the pulse pair technique must be understood. This paper analyzes the effect of radar system pulse to pulse phase jitter and signal spectrum skew on the pulse pair algorithm performance. Phase jitter effects may be significant when the weather return signal to clutter ratio is very low and clutter rejection filtering is attempted. The analysis can be used to develop design specifications for airborne radar system phase stability. The paper also shows that weather return spectrum skew can cause a significant bias in the pulse pair mean windspeed estimates, and that the poly pulse pair algorithm can reduce this bias. It is suggested that use of a spectrum mode estimator may be more appropriate in characterizing the windspeed within a radar range resolution cell for detection of hazardous windspeed gradients.

REAL TIME PROCESSING OF RADAR RETURN ON A PARALLEL COMPUTER^[15] D. D. Aalfs

NASA is working with the FAA to demonstrate the feasibility of pulse Doppler radar as a candidate airborne sensor to detect low altitude windshears. The need to provide the pilot with timely information about possible hazards has motivated a demand for real time processing of radar return. This thesis investigates parallel processing as a means of accommodating the high data rates required. A PC based parallel computer, called the transputer, is used to investigate issues in real time concurrent processing of radar signals. A transputer network is made up of an array of single instruction stream processors that can be networked in a variety of ways. They are easily reconfigured and software development is largely independent of the particular network topology. The performance of the transputer is evaluated in light of the computational requirements. A number of algorithms have been implemented on the transputers in OCCAM, a language specially designed for parallel processing. These include signal processing algorithms such as the FFT, pulse-pair, and AR modeling, as well as routing software to support concurrency. The most computationally intensive task is estimating the spectrum. Two approaches have been taken on this problem,

the first and most conventional of which is to use the FFT. By using table look-ups for the basis function and other optimizing techniques an algorithm has been developed that is sufficient for real time. The other approach is to model the signal as an autoregressive process and estimate the spectrum based on the model coefficients. This technique is attractive because it does not suffer from the spectral leakage problem inherent in the FFT. Benchmark tests indicate that autoregressive modeling is feasible in real time.

AIRBORNE PULSED DOPPLER RADAR DETECTION OF LOW ALTITUDE WINDSHEAR - A SIGNAL PROCESSING PROBLEM ^[16]

E. G. Baxa, Jr.

Low level windshear is a major safety hazard to airline operations in near-terminal area. Presently research is underway to determine how to best design a new generation high resolution airborne pulse Doppler weather radar capable of detecting hazardous situations. Applications of modern signal processing theory and techniques are being investigated to provide a reliable airborne remote sensor capable of operating in very low weather-signal to ground-clutter ratio environments. This paper includes a brief overview of signal processing research related to ground-based radar systems currently being procured by the FAA. Major signal processing problems related to development of an airborne system are discussed, including how best to reject the effects of ground clutter, how to estimate windfields, and how to determine when a hazardous situation exists. The goal is to provide an automated system capable of giving a pilot advance warning so that avoidance maneuvers are possible. This represents a challenging signal processing problem and involves spectral estimation, expert systems, real-time algorithm implementations, and performance prediction and evaluation.

SPECTRUM MODAL ANALYSIS FOR THE DETECTION OF LOW-ALTITUDE WINDSHEAR WITH AIRBORNE DOPPLER RADAR ^[17]

M. W. Kunkel

A major obstacle in the estimation of windspeed patterns associated with low-altitude windshear using an airborne pulsed Doppler radar system is the presence of strong levels of ground clutter which can bias a windspeed estimate. Typical solutions attempt to remove the clutter energy from the return through clutter rejection filtering. Proposed is a method whereby both the weather and clutter modes present in a return spectrum can be identified and classified to yield an unbiased estimate of the weather mode without the need for clutter rejection filtering. An attempt will be made to show that modeling through a second order extended Prony approach is sufficient for the identification of the weather mode. A pattern recognition approach to windspeed estimation from the identified modes is derived and applied to both simulated and actual flight data. Comparisons between windspeed estimates derived from modal analysis and the pulse-pair estimator are included as well as associated hazard factors. Also included is a computationally attractive method for estimating windspeeds directly from the coefficients of a second-order autoregressive model. Extensions and recommendations for further study are included.

SIGNAL PROCESSING FOR AIRBORNE DOPPLER RADAR DETECTION OF HAZARDOUS WINDSHEAR AS APPLIED TO NASA 1991 RADAR FLIGHT EXPERIMENTAL DATA ^[19]

E. G. Baxa, Jr.

Radar data collected during the 1991 NASA flight tests have been selectively analyzed to support research directed at developing both improved as well as new algorithms for detecting hazardous low-altitude windshear. Analysis of aircraft attitude data from several flights indicated that platform stability bandwidths were small compared to the data rate bandwidths which should support an assumption that radar returns can be treated as short time stationary. Various approaches at detection of weather returns in the presence of ground clutter are being investigated. Non-conventional clutter rejection through spectrum mode tracking and classification algorithms is a subject of continuing research. Based upon autoregressive modelling of the radar return time sequence this approach may offer an alternative to overcome errors in conventional pulse-pair estimates. Adaptive filtering is being evaluated as a means of rejecting clutter with emphasis on low signal-to-clutter ratio situations, particularly in the presence of discrete clutter interference. An analysis of out-of-range clutter returns is included to illustrate effects of ground clutter interference due to range aliasing for aircraft on final approach. Data are presented to indicate how aircraft groundspeed might be corrected from the radar data as well as point to an observed problem of groundspeed estimate bias variation with radar antenna scan angle. A description of how recorded clutter return data are mixed with simulated weather returns is included. This enables the researcher to run controlled experiments to test signal processing algorithms. In the summary, research efforts involving improved modelling of radar ground clutter returns and a Bayesian approach at hazard factor estimation are mentioned.

CHARACTERIZATION OF URBAN GROUND CLUTTER WITH NEW GENERATION AIRBORNE DOPPLER WEATHER RADAR ^[20]

A. I. Mackenzie, E. G. Baxa, Jr., and S. D. Harrah

To characterize urban ground clutter as seen by an airborne X-band Doppler weather radar, data have been collected while viewing the ground in the vicinity of airports at Philadelphia (PHL), Denver (DEN), and Orlando (MCO). These flights were made as part of a joint NASA/FAA program to determine the feasibility of using such a radar to detect low-altitude wind shears. Since the experimental radar was built as a wind shear detector, the ground returns which are of interest in this paper are called clutter returns, according to the intended principal use of the radar. Analysis of the data has yielded information about Normalized Radar Cross Section (NCRS), spectral width and location of clutter spikes in the velocity spectrum and the effects of out-of-range clutter returns.

NEW SIGNAL PROCESSING DEVELOPMENTS IN THE DETECTION OF LOW-ALTITUDE WINDSHEAR WITH AIRBORNE DOPPLER RADAR ^[21]

E. G. Baxa, Jr., Y.C. Lai, and M. W. Kunkel

Airborne weather radar is being developed to detect hazardous low-altitude windshear which has been a major contributing factor in many airline crashes in this country. One of the major challenges is development of signal processing algorithms which will perform satisfactorily when the weather return signal power to interfering ground clutter return power is very low. This paper describes two basic approaches which are under investigation. One approach is to estimate windspeed from the radar returns using an extended Prony based method without a clutter rejection pre-filter, since the filtering process itself can reduce the weather signal below useful levels. Alternatively, improved clutter pre-filtering techniques are being investigated based on an adaptive noise canceller implementation of the LMS algorithm. Results are presented to illustrate some of the capabilities of each. Also described is a method for merging flight experimental clutter return data with a simulated microburst return based on a radar measured windfield. This allows very rare low reflectivity weather events to be studied in the presence of actual clutter data.

ON THE APPLICATION OF THE LMS-BASED ADAPTIVE NOISE CANCELLER IN A NONSTATIONARY ENVIRONMENT ASSOCIATED WITH AIRBORNE DOPPLER WEATHER RADAR ^[22]

Y.C. Lai and E. G. Baxa, Jr.

Filtering nonstationary signals is a major area of application for adaptive systems. This paper investigates use of the LMS based adaptive noise canceller as a process decorrelator in a nonstationary signal and noise environment. In an airborne Doppler weather radar application, ground clutter and weather returns are treated as two uncorrelated nonstationary processes, and under severely low signal-to-clutter ratio (SCR) situations, it is shown that the adaptive noise canceller exhibits performances superior to that of a fixed, nonadaptive system in terms of ground clutter suppression and estimates of weather parameters.

A STUDY OF THE CORRELATION DIMENSION OF WEATHER AND GROUND CLUTTER RETURNS IN AIRBORNE RADAR ^[23]

K. D. Barnett and E. G. Baxa, Jr.

Recent efforts in the radar field include developing airborne radar systems for use during takeoff and landing for avoidance of hazardous windshear conditions. Experience has shown that the most critical problem is the discrimination between ground clutter and slow moving weather. Simple frequency domain filters may be ineffective in this case, since the weather and clutter returns are concentrated in the same frequency bands. Here we explore one possible discriminant: the correlation dimension.

DESIGNING CLUTTER REJECTION FILTERS WITH COMPLEX COEFFICIENTS FOR AIRBORNE PULSED DOPPLER WEATHER RADAR ^[24]

D. A. Jamora

A major problem for airborne pulse Doppler weather radar is ground clutter returns, especially for a "lookdown" radar operating at low altitudes, due to the low power level of weather returns. Because of the velocity discrimination capabilities of Doppler radar, ground clutter rejection filtering is reduced to a simple cancellation of returns near and around zero Doppler, usually through a high-pass filter. Observation of clutter spectra obtained from the NASA Wind Shear Flight Experiments of 1991-92 shows that the clutter mode can be shifted from zero Doppler even after antenna pointing compensation. This may occur at short radar ranges due to sidelobe returns and at other ranges due to large RCS ground targets that are within the antenna beam width but not at boresight. In order to compensate for the near range shifting trend, a filtering scheme is explored which makes use of a filter with complex coefficients so that the stopband notch of the filter can be located at any Doppler frequency. Several clutter mode tracking algorithms are considered to estimate the shift position. From the examination of the flight data, the sidelobe returns of the closer ranges were found to be spread in frequency such that complex filtering provides little improvement, but when a dominant clutter mode is present complex filtering is able to significantly increase clutter rejection over that of a fixed notch filter.

ON THE ESTIMATION OF THE CORRELATION DIMENSION AND ITS APPLICATION TO RADAR REFLECTOR DISCRIMINATION ^[25]

K. D. Barnett

Recently, system theorists have recognized that lower order systems of nonlinear differential equations can give rise to solutions which are neither periodic, constant, nor predictable in steady state, but which are nonetheless bounded and deterministic. This behavior, which was first described in the study of weather systems, has been termed "chaotic". Much study of chaotic systems has concentrated on analysis of the systems' phase space attractors. It has been recognized that invariant measures of the attractor possess inherent information about the system. One such measure is the dimension of the attractors. The dimension of a chaotic attractor has been shown to be noninteger, leading to the term "strange attractor"; the attractor is said to have a fractal structure. The correlation dimension has become one of the most popular measures of dimension. However, many problems have been identified in correlation dimension estimation from time sequences. The most common methods for obtaining the correlation dimension have been least squares curve fitting to find the slope of the correlation integral and the Takens Estimator. However, these estimates show unacceptable sensitivity to the upper limit on the distance chosen. Here a new method is proposed which is shown to be rather insensitive to the upper limit and to perform in a very stable manner, at least in the absence of noise. The correlation dimension is also shown to be an effective discriminant in distinguishing between radar returns resulting from weather and those from the ground. The weather returns are shown to have a correlation dimension generally between 2.0 and 3.0, while ground returns have a correlation dimension exceeding 3.0.

DESCRIPTION AND AVAILABILITY OF AIRBORNE DOPPLER RADAR DATA^[26] S. D. Harrah, E.M. Bracalente, P.R. Schafner, and E.G. Baxa, Jr.

An airborne, forward-looking, pulse Doppler radar has been developed in conjunction with the joint FAA/NASA Wind Shear Program. This radar represents a first in an emerging technology. The radar was developed to assess the applicability of an airborne radar to detect low altitude hazardous wind shears for civil aviation applications. Such a radar must be capable of looking down into the ground clutter environment and extracting wind estimates from relatively low reflectivity weather targets. These weather targets often have reflectivities several orders of magnitude lower than the surrounding ground clutter. The NASA radar design incorporates numerous technological and engineering achievements in order to accomplish this task. This presentation will describe the radar hardware and software in more detail, summarize the wide variety of radar data collected, and discuss procedures through which individuals may obtain copies of this data. Examples of some of the analysis performed to date will also be presented.

SIGNAL PROCESSING ASPECTS OF WINDSHEAR DETECTION^[27] D. D. Aalfs, E. G. Baxa, Jr., and E. M. Bracalente

Low-altitude windshear (LAWS) has been identified as a major hazard to aircraft, particularly during takeoff and landing. The Federal Aviation Administration has been involved with developing technology to predict and detect LAWS. A key element in this technology is the pulse Doppler weather radar which is essentially a new generation weather radar equipped with signal and data processing to provide to provide timely information about possible hazardous conditions. Current deployment of the NEXRAD and Terminal Doppler Weather Radar (TDWR) systems with windshear algorithms has been accompanied with investigation by NASA of the feasibility of airborne pulse Doppler radar as a forward looking windshear hazard sensor. This paper discusses some of the signal processing issues associated with windshear detection from an airborne radar platform. Characteristics of a NASA experimental radar are compared and contrasted to the NEXRAD and TDWR systems. The real time processing demands are described in the context of an airborne system. Problems of rejection of the ground clutter return peculiar to the airborne environment are also discussed.